Argonne National Laboratory
HEP Theory Group

Summary of Research Activities

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Argonne National Laboratory

KICP and EFI, University of Chicago

DOE Review, Argonne HEP Division, April 26, 2007

Composition of the Group

- Theory Group has five permanent staff members:

  E. Berger (Collider physics, QCD, BSM)
  G. Bodwin (QCD, Quarkonium physics)
  T. Tait (Collider physics, BSM, Cosmology)
  C. Zachos (Abstract Physics)
  C. Wagner (Collider Physics, BSM, Cosmology)

- The group also counts regularly with two or three postdoctoral fellows as well as a few students.

Productivity

- Group has been very productive on a broad range of areas of physics. In the last five years, staff members have published 100 articles in refereed journals. This includes many articles published with more than one staff member as a co-author. Independent postdoc articles also quite significant in number (more than 40 articles).

- Theory group is very strong in the areas related to phenomenology of particle physics: Collider physics, QCD, Higgs physics, heavy quarkonia and beyond the standard model phenomenology.

- The group has produced many relevant articles in the areas of cosmology and astroparticle physics, in particular on the questions of dark-matter and baryogenesis.

- The group has also contributed to non-perturbative studies of QCD, as well as the analysis of other non-perturbative configurations

Postdocs

- Activities of the group have been reinforced by several young postdoctoral fellows.
- Most of them have found excellent positions an carry successful careers after their stay at Argonne
- Notable cases are John Campbell, Csaba Balazs, Puneet Batra, Cheng-Wei Chiang, David Kaplan, Jing Jiang, Michael Klasen, Jungil Lee, Geraldine Servant, Irina Mocioiu and Tim Tait.
- Excellent group of postdocs joined us in last years: B. Lillie (BSM, phenomenology) and P. Nadolsky (QCD, collider physics). We recently hired Xavier Garcia i Tormo (quarkonium physics), who joined us in September, and Ayres Freitas (collider physics), who will join us in the fall.
- An offer was also made to Jay Hubisz, who got a Director postdoctoral position (Sponsored by E. Berger). Obtention of this fellowship, after a Lab-wide competition, should be considered a big success.

Contact with the University of Chicago

- One of the staff members, C.W., has a joint position with the University of Chicago and is teaching a course per year. He is now appointed as a full professor there, holding a tenured, half-time position.

- Several students from the UofC, have been working regularly at the Theory Group. Examples are A. Menon, who will move in the fall to the Univ. of Michigan, Ann Arbor and A. Medina, N. Shah and J. Shu who also worked regularly at the group.

- Successful Argonne/UofC joint postdoctoral program, mantained for the last four years. All the postdoctoral fellows participating in this program obtained professorships in different Universities around the world, soon after leaving Argonne (Kaplan), or during their stay at the laboratory (Chiang, Servant).

- Recent postdoc (Mocioiu) got a tenure-track position at Penn State . Ben Lillie holds now a joint position and Ayres Freitas will hold a similar position, supported by the Joint Insitute on Collider Physics (recent offer from Univ. of Pittsburgh).

Joint Institute on Collider Physics

- Joint Initiative of Theorists and Experimentalists at Argonne and the University of Chicago (E. Berger, J. Proudfoot, T. Tait, B. Wagner, C. Wagner (PI), H. Frisch (PI), F. Merritt, C.Pilcher, J. Pilcher), $108K
- Idea:
- Strengthen the ties between the Argonne and University of Chicago faculty interested in collider physics issues
- Bring visitors and postdocs with expertise in collider physics
- Organize Workshops
- Contribute to the start of the LHC Analysis Center

Joint Theory Institute Awards

- Lab-wide competition for funding for joint projects with the Univ. of Chicago
- Two proposals from the Theory Group were recently selected:
  - Collider Physics (E.L. Berger (Argonne), J. Rosner (Univ. of Chicago)), $87K
  - Non-Perturbative QCD, AdS/CFT and Brane Dynamics (D. Sinclair, C. Roberts, C. Wagner, C. Zachos, (Argonne) and J. Harvey, D. Kutasov (Univ. of Chicago)), $108K
- These awards should allow to bring postdocs and visitors and to organize workshops in coordination with the University of Chicago in the coming year

Visiting Scientists

- During the last year, we have profitted from the presence of two long-term visiting scientists:

  - Zack Sullivan (partially supported by the joint Argonne/UofC collider institute, now Adjunct Assistant Professor at SMU)
  - Jian-Wei Qiu (Professor at Iowa State Univ., on sabbatical leave)

- We have also profitted from frequent visits from H. Lipkin, J. Uretsky and G. Ramsey.

Joint Faculty Positions with NW

- The Argonne HEP Group conducted a search for joint junior faculty positions with Northwestern Univ.
- An open search was conducted, with the aim of hiring two phenomenologists, doing physics related to the LHC
- Search Committee: E.L. Berger, G. Bodwin, T. LeCompte, B. Wicklund and C.E.M. Wagner (plus four NW faculty members)
- Tim Tait decided to take advantage of this opportunity and applied for the job
- Two candidates were selected and an offer is going to be made within the following days. The process has already received approval from the NW Dean, and a decision from the Provost is expected soon.
- I can only say, without violating the confidentiality of the process, that the two joint positions will come at little or no additional cost to the HEP Division

Organization of Workshops and Schools

- The group has organized seven international workshops at the Argonne HEP Division in the last five years.

- Subjects included
- Higgs, Supersymmetry, extra dimensions (E. Berger, T. Tait and C. Wagner)
- Neutrino Physics (E. Berger, M. Goodman, C. Wagner)
- QCD in extreme environments (D.K. Sinclair)
- Brane Dynamics (C. Zachos)

- It has also hosted Greater Chicagoland Meetings (G. Bodwin, E. Berger, C. Wagner) and Lab-wide Theory Meetings (E. Berger).

- All these activities have greatly increased the visibility of the group.

Theory Budget

- The addition of new postocs and junior faculty has been based on temporary funding and/or on diversifying our workforce via joint positions with local Universities
- In the last years, however, we have seen a sizable reduction in the number of postdocs supported by the base program
- We have also lacked a visitor program, or a fixed budget
- Actually, the budget problem resulted in the lay-off of a highly respected, and productive staff physicist, Don Sinclair, who served the laboratory for 22 years.
- Even taking into account this sad departure, and thanks to a recent, modest budget increase, our budget is now just enough to pay staff salaries this year. But we have limited travel funds and we are unable to support any postdocs or visitors.
- Our priority is to reverse this situation. Optimal goal would be to obtain the funds necessary to support visitors as well as two or three postdocs with the base program.
- We hope this issue receives the serious consideration it deserves.

Why should the DOE support the Argonne Theory Group ?

Because we are doing very good work, in accordance with the HEP National priorities

2006--2007

Theory Group Research Highlights

QCD Analyses

Solution of the Puzzle of $e^+e^- \to J/\psi + \eta_c$

G.T. Bodwin, D. Kang, J. Lee

(Phys. Rev. D **74**, 014014 (2006))

G.T. Bodwin, J. Lee, T. Kim, C. Yu

(hep-ph/0611002)

- Experiment
  Belle: $\sigma(e^+e^- \to J/\psi + \eta_c) \times B_{>2} = 25.6 \pm 2.8 \pm 3.4$ fb.
  BABAR: $\sigma(e^+e^- \to J/\psi + \eta_c) \times B_{>2} = 17.6 \pm 2.8^{+1.5}_{-2.1}$ fb.
- NRQCD at LO in α_s and v
  Braaten, Lee: $\sigma(e^+e^- \to J/\psi + \eta_c) = 3.78 \pm 1.26$ fb.
  Liu, He, Chao: $\sigma(e^+e^- \to J/\psi + \eta_c) = 5.5$ fb.
- Zhang, Gao, Chao: Corrections at NLO in α_s produce a K factor of approximately 1.96.
- We used a potential model to compute a key NRQCD matrix element that enters into relativisitic corrections to many processes.
  This was the first calculation with sufficient accuracy to be of phenomenolgical use.
- Resummed relativistic corrections to $\sigma(e^+e^- \to J/\psi + \eta_c)$ produce a combined K factor of 4.15.
- Preliminary result: $\sigma(e^+e^- \to J/\psi + \eta_c) = 17.5 \pm 5.7$ fb.
- It appears that a long-standing puzzle has been solved.

Exclusive Two-Vector-Meson Production in e^+e^- Annihilation

G.T. Bodwin, E. Braaten, J. Lee, C. Yu

(Phys. Rev. D **74**, 074014 (2006))

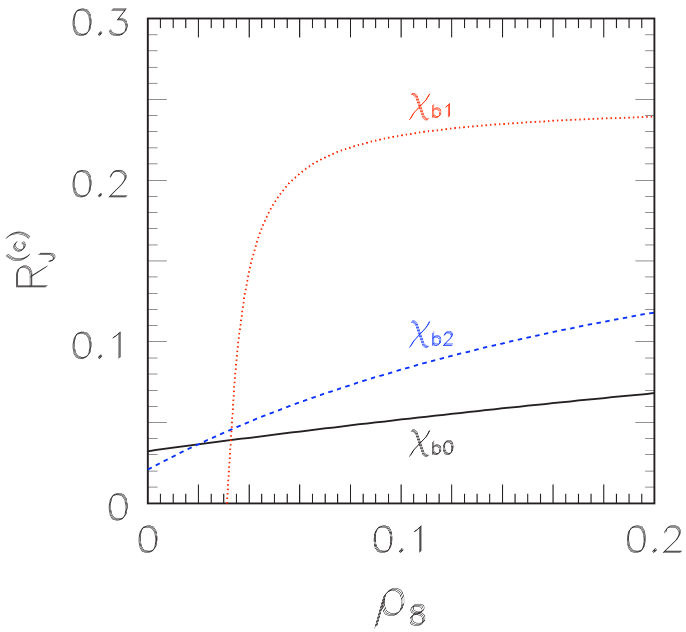
- Motivated by recent measurements by BABAR of exclusive production of two vector mesons.
- Calculated the production cross sections for all combinations of ρ^0, ω, ϕ, J/ψ, $\psi(2S)$.
- Calculated the fragmentation amplitudes using VMD.
  - VMD incorporates some corrections of higher order in α_s and v.
  - Minimizes theoretical uncertainties.
- For light mesons, the nonfragmentation amplitudes are negligible (order $\Lambda^2_{\rm QCD}/E^2_{\rm beam}$).
- Calculated the nonfragmentation amplitudes for the J/ψ and $\psi(2S)$ using NRQCD.
- Included effects from the finite width of the ρ^0 by using the experimentally-measured line shape. Included effects from the finite width of the ϕ by using a Breit-Wigner form.
- Also computed the rates using the BABAR cuts on the production angle and the ρ^0 mass.
- Our results for $\rho^0 + \rho^0$ and $\rho^0 + \phi$ are in good agreement with the measurements of BABAR.

Inclusive Charm Production in χ_b Decays

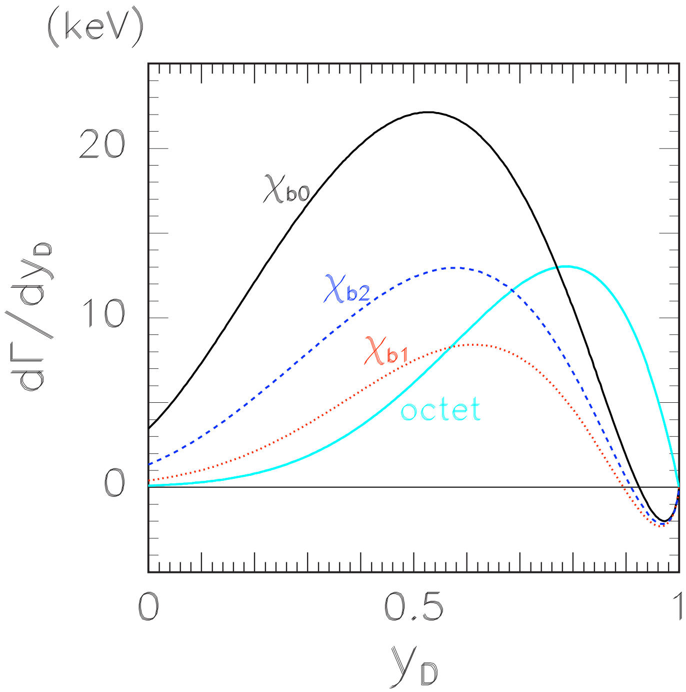
G.T. Bodwin, E. Braaten, D. Kang, J. Lee

(hep-ph/0704.2559)

- Calculation motivated by a request from CLEO.
- Calculated the decay rates for $\chi_{bJ} \to c\bar{c} + X$ for $J = 0, 1, 2$ at order α_s^3 using the NRQCD formalism.
- Calculated the total charm rate and the charm rate differential in the momentum of the c-quark.
- The rate in the color-singlet channel is IR divergent, but, in the NRQCD formalism, the divergence is absorbed into a color-octet matrix element.
- All of the 3-body phase space integrals were calculated analytically for a finite c-quark mass.



- The ratio of rates $R_J^{(c)} = \Gamma^{\rm charm}/\Gamma^{\rm total}$ depends on the ratio of matrix elements $\rho_8 = m_b^2 \langle \mathcal{O}_8 \rangle_{\chi_b} / \langle \mathcal{O}_1 \rangle_{\chi_b}$.
- Measurements of $R_J^{(c)}$ can be used to determine the color-octet matrix element.



- Convolutions of our results with a quark fragmentation function give the D meson spectrum.
- $y = p_D/p_D^{\max}$.
- Unphysical negative cross sections near the kinematic endpoint signal the breakdown of the α_s expansion.
  Can be cured by resummation of logs.
  Work in progress.

Parton distributions at small x

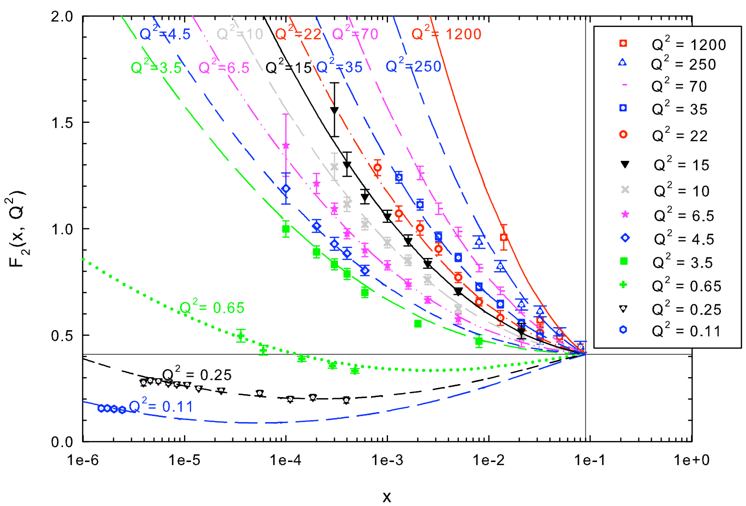
Berger, Block, Tan, Phys Rev Letters **97**, 252003 (2006) and hep-ph/0703003 $\rightarrow$ PRL

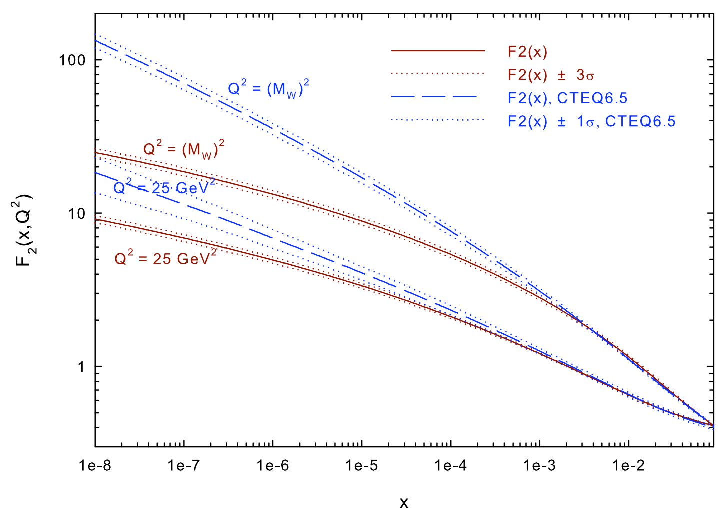
- Understanding the x dependence of quark, antiquark, and gluon distributions at small x is crucial for reliable predictions at the LHC, and of very high energy ν interaction rates (e.g., Anita and Rice)
- Almost sole reliance now on the assumed inverse power $x^{-\lambda}$ behavior built into CTEQ, MRST, ...
- Excellent quantitative fit (6 parameters) obtained for x and Q^2 dependences of ZEUS DIS structure function $F_2^p(x, Q^2)$, for $x < 0.1$ – figure below – with a $\ln^2(1/x)$ expansion at small x, based on analyticity and unitarity arguments (Froissart bound)
- Predictions at $x \sim 10^{-8}$ are a factor of 5 smaller than CTEQ for $Q = M_W$, electroweak scale relevant at the LHC and for very high energy ν interactions
- Interesting theoretical questions about parton saturation and/or gluon recombination at small x

Parton distributions at small x

Berger, Block, Tan, Phys Rev Letters **97**, 252003 (2006) and hep-ph/0703003 → PRL

- (a) Fit to $F_2^p(x, Q^2)$ vs. x for 13 values of Q^2, $0.11 \leq Q^2 \leq 1200$ GeV^2. χ^2/d.f.=1.09, for 169 degrees of freedom (d.f.)
- (b) $F_2^p(x, Q^2)$ vs. x at $Q^2 = 25$ GeV^2 and $Q^2 = M_W^2$, along CTEQ6.5M expectations. Note factor of 5 difference at $x \sim 10^{-8}$ for $Q = M_W$



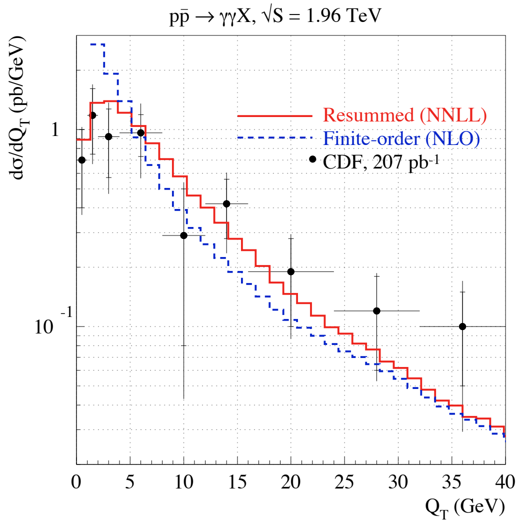


$\gamma\gamma$ *Production: QCD and the Higgs Signal*

Berger, Nadolsky, Balazs, Yuan Phys Lett **B637** 235 (2006)

and hep-ph/0702003 $\rightarrow$ Phys Rev D and arXiv:0704.0001 $\rightarrow$ Phys Rev D

- Fully differential calculation ($M_{\gamma\gamma}$, Q_T, y, θ, ϕ) of high mass continuum $\gamma\gamma$ production in NLO perturbative QCD, ($q\bar{q}$, qg, and gg subprocesses), along with NNLL resummation of initial state soft-gluon radiation to all orders in α_s — culmination of a multi-year effort
- New theoretical issues in resummation: 2-loop process in $gg \rightarrow \gamma\gamma X$
- Good agreement with CDF and D0 data from FNAL and predictions for more differential, correlation studies



Note the improvement of the resummed calculation compared with the divergent NLO expectation at small transverse momentum Q_T

Hint of disagreement with CDF data when $Q_T > 25$ GeV is well understood

- arises from the region $Q_T > Q$
- different physics/resummation is needed for $Q_T > Q$: $q \rightarrow \gamma\gamma q$ fragmentation

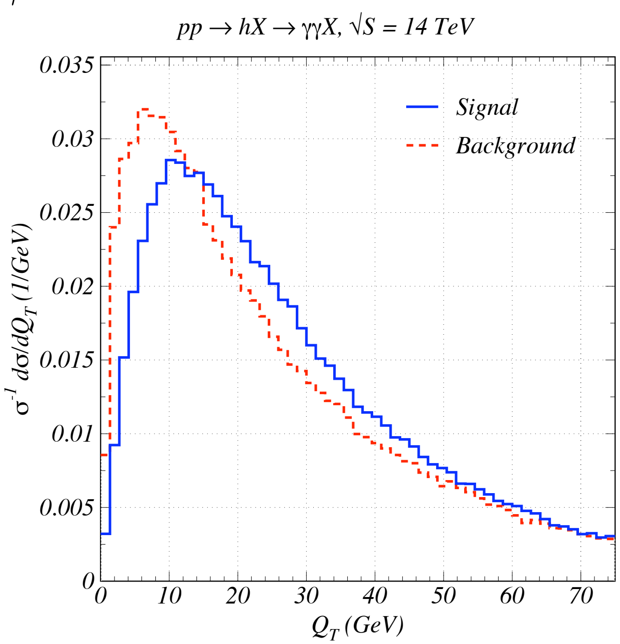
$\gamma\gamma$ *Production: QCD and the Higgs Signal*

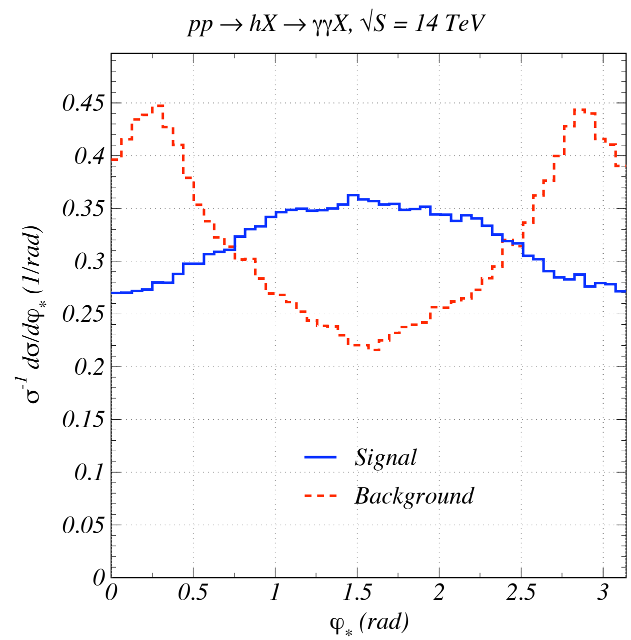
Berger, Nadolsky, Balazs, Yuan Phys Lett **B637** 235 (2006)

and hep-ph/0702003 $\longrightarrow$ Phys Rev D and arXiv:0704.0001 $\longrightarrow$ Phys Rev D

- Predictions for distributions of high-mass $\gamma\gamma$ pairs at the LHC
- Comparisons with expectations from $h \rightarrow \gamma\gamma X$
- Suggest cuts to enhance S/B of the Higgs signal based on different spin structure of the signal and QCD background

Normalized Higgs signal and $\gamma\gamma$ continuum, both at NNLL; $m_H = 130$ GeV; continuum $128 < M_{\gamma\gamma} < 132$ GeV



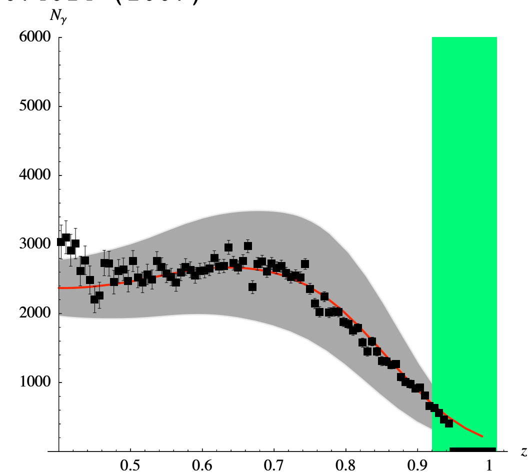


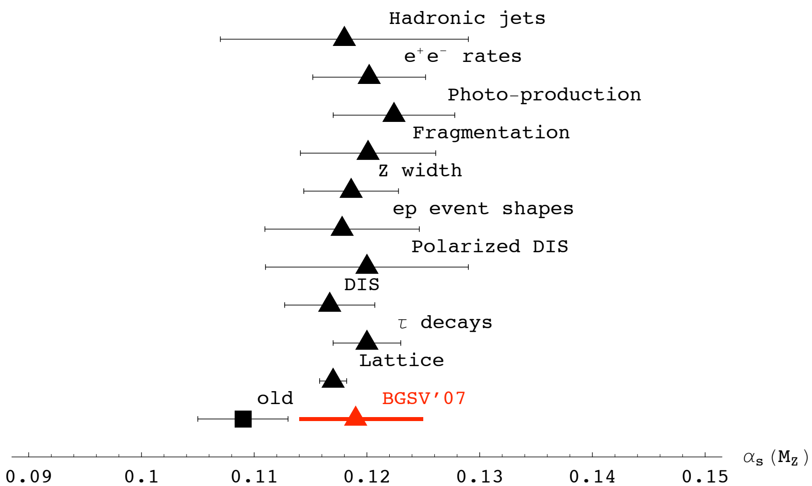
Xavier Garcia i Tormo

Radiative Υ decays ($\Upsilon \to X\gamma$)

N. Brambilla, X. Garcia i Tormo, J. Soto and A. Vairo, Phys. Rev. D **75**, 074014 (2007)

Recently a good theoretical description from QCD of the photon spectrum has been achieved. Comparison with recent CLEO data is excellent (figure to the right). The photon spectrum can now be used to reliably study the properties of the decaying quarkonium and to extract SM parameters.





An improved α_s extraction has been obtained. The extraction takes into account color octet contributions and avoids any model dependence. The new result compares well with extractions from other processes (figure to the left, square is old result from Υ decays).

QCD static energy

N. Brambilla, X. Garcia i Tormo, J. Soto and A. Vairo, Phys. Lett. B **647**, 185 (2007)

Computation of the 4th order logarithmic correction ($\alpha_s^5 \log \alpha_s$ terms).

Higgs and Beyond the

Standard Model Physics

Higgs $\to W^+W^- \to l^+l^- + E_T^{\rm miss}$

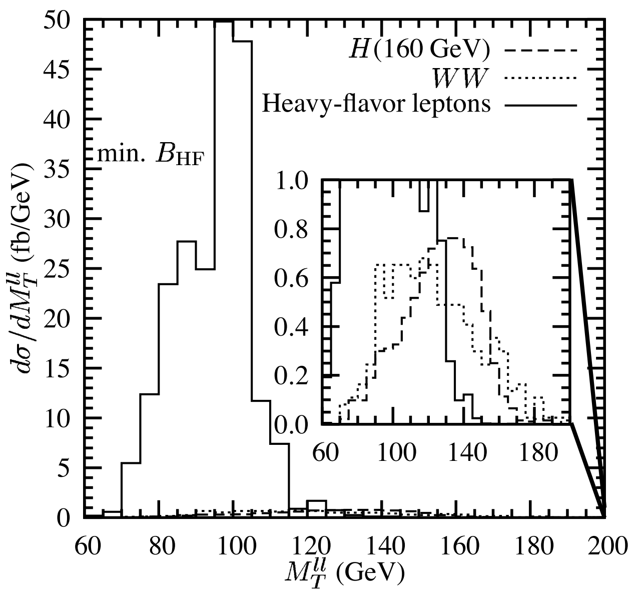
Berger and Sullivan Phys Rev **D74**, 033008 (2006) and AIP Conf.Proc. **870**, 258-261 (2006)

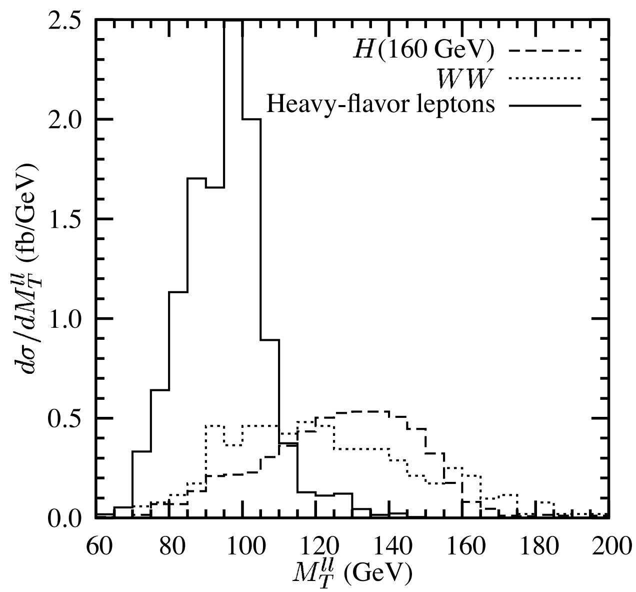
- Full calculation, including detector simulations, of the signal and SM backgrounds, with new emphasis on the important role of heavy flavor (HF) decays, e.g., $b \to lX$, at the Tevatron and LHC
- Standard model backgrounds included:
  - ‘irreducible’ — at least two ‘isolated’ leptons plus $E_T^{\rm miss}$: continuum $WW^* \to l^+l^-\nu\bar{\nu}$; $WZ/ZZ \to l^+l^-\nu X$; $t\bar{t} \to WWb\bar{b}$; ‘single top’ $qg \to Wt \to WWb$;...
  - ‘reducible’ — the (second) lepton(s) and $E_T^{\rm miss}$ from heavy flavor decay: $Wb\bar{b} \to l\nu b\bar{b}$; $Wc\bar{c}$, Wc,..., and inclusive $b\bar{b}/c\bar{c}$
- Isolation requirement is insufficient to obtain adequate S/B. HF must be reduced by a sequence of physics cuts
- New hard cut on the E_T of the second lepton proposed
- Interactions with ATLAS experimenters (e.g., B. Mellado, U. Wisc.)
- Now investigating trilepton final states, important for SUSY searches

Higgs $\rightarrow W^+W^- \rightarrow l^+l^- + E_T^{\rm miss}$

Berger and Sullivan Phys Rev **D74**, 033008 (2006) and AIP Conf.Proc. **870**, 258-261 (2006)

- (a) Opposite-sign dilepton transverse mass distribution for a 160 GeV Higgs boson, the continuum WW background, and the sum of heavy-flavor backgrounds (HFB) at ATLAS. The inset shows a blow-up of the signal region
- (b) Same as (a) but after the cut on the next-to-leading lepton E_{Tl_2} is raised from 10 GeV to 20 GeV





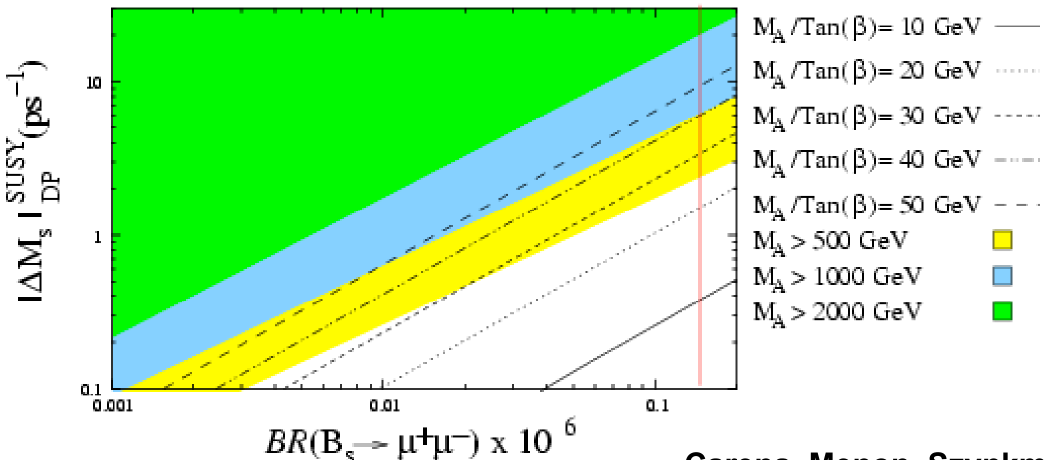
The $B_s \to \mu^+\mu^-$ constraint on double penguin contributions to ΔM_s in MSSM

- For uniform squark masses: $\frac{Br(B_s \to \mu^+\mu^-)}{\Delta M_s} \propto \frac{\tan^2\beta}{M_A^2}$
- Colored contours correspond to the extreme values:

$$\frac{M_3}{2} \approx M_{\tilde{Q}} \approx \frac{\mu}{2} \approx \frac{A_t}{3}$$

- The Experimental bound: $Br(B_s \to \mu^+\mu^-) < 1.5 \times 10^{-7}$

CDF collaboration: hep-ex/0508058



Carena, Menon, Szynkman,Noriega,C.W. **hep-ph/0603106**

Tight upper bound on $|\Delta M_s|$ within minimal flavor violating SUSY Models. Recent D0 result, hep-ex/0603029, consistent with this result.

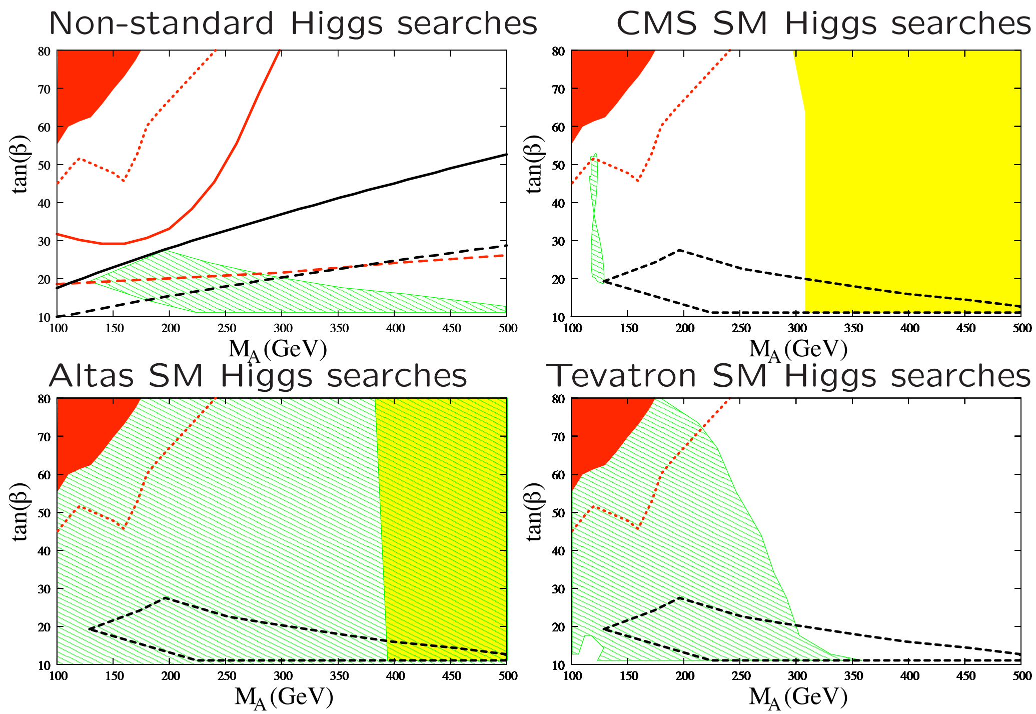
Interplay of B and Higgs Physics in the MSSM

M. Carena, A. Menon and C. Wagner, PRD74:015009, 2006 & arXiv:0704.1143 [hep-ph]

Projection of constraints in the $M_A - \tan\beta$ plane for large X_t and small μ

$M_{SUSY} = 2.4\text{TeV}, \;\; |M_3| = 0.8 M_{SUSY}, \;\; \mu = -100\text{GeV}, \;\; X_t = A_t - \frac{\mu}{\tan\beta} = 1\text{TeV}$

Fig	Green	Yellow
1	B-phys. allowed	N.A.
2	$q\bar{q}h(h \to \tau\bar{\tau})$	$ggh(h \to \gamma\gamma)$
3	$q\bar{q}h(h \to \tau\bar{\tau})$	$ggh(h \to \gamma\gamma)$
4	$W/Zh(h \to b\bar{b})$	N.A.



- Red region exclude by CDF by inclusive searches for $A \to \tau\tau$ at 1 fb^{-1}. Regions surrounded by black dashed curves in Fig. 2,3,4 are B-physics allowed

Line	solid	dashed	dotted
Excluded above red for inclusive $A \to \tau\tau$	4 fb^{-1} Proj. Tevatron	30 fb^{-1} Proj. LHC	1 fb^{-1} D0
Excluded below black for $B_s \to \mu^+\mu^-$	4 fb^{-1} Proj. Tevatron	10 fb^{-1} Proj. LHC	N.A.

Interplay of B and Higgs Physics in the MSSM

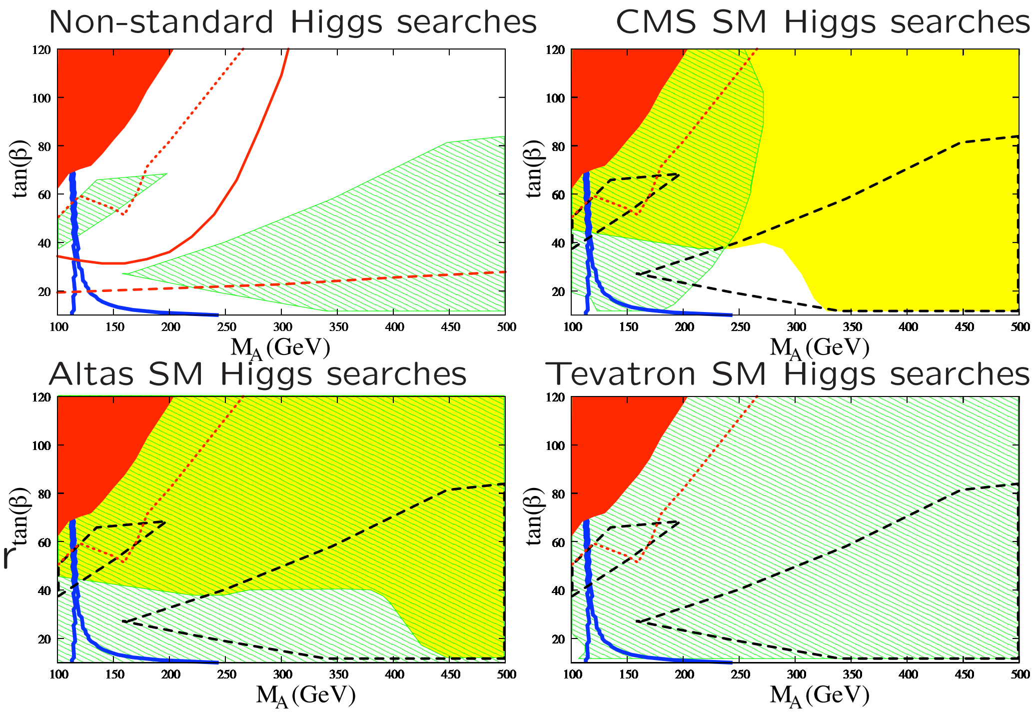
M. Carena, A. Menon and C. Wagner, PRD74:015009, 2006 & arXiv:0704.1143 [hep-ph]

Projection of constraints in the $M_A - \tan\beta$ plane for Minimal Mixing

The SUSY parameters are same except $X_t = 0$ $\mu = 1.5 M_{SUSY}$ and $M_{SUSY} = 2$ TeV.

Fig	Green	Yellow
1	B-phys. allowed	N.A.
2	$q\bar{q}h(h \to \tau\bar{\tau})$	$ggh(h \to \gamma\gamma)$
3	$q\bar{q}h(h \to \tau\bar{\tau})$	$ggh(h \to \gamma\gamma)$
4	$W/Zh(h \to b\bar{b})$	N.A.

- Red region exclude by CDF by inclusive searches for $A \to \tau\tau$ at 1 fb^{-1}. Regions surrounded by black dashed curves in Fig. 2,3,4 are B-physics allowed. Region under blue curve exclude by LEP Higgs mass bound. $X_t = 0 \Rightarrow B_s \to \mu^+\mu-$ constraint is weak

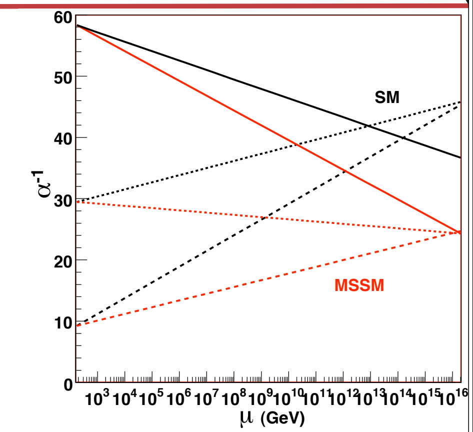


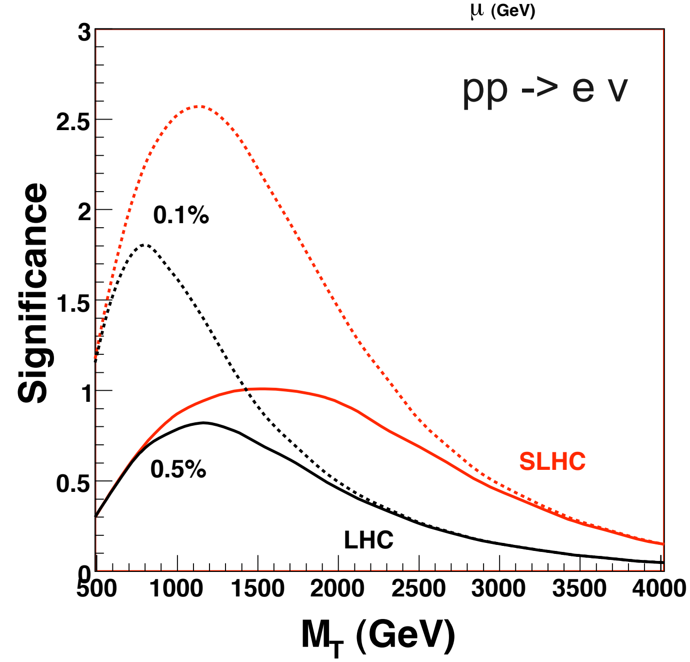
Line	solid	dashed	dotted
Excluded above red for inclusive $A \to \tau\tau$	4 fb^{-1} Proj. Tevatron	30 fb^{-1} Proj. LHC	1 fb^{-1} D0

Testing Grand Unification at the LHC

Rainwater, Tait
hep-ph/0701093

- One of the remarkable properties of the MSSM is that it seems to predict the gauge couplings should unify at large scales, and predicted by Grand Unified theories.
- At the LHC, by measuring the gauge couplings at large momentum transfer in SM reactions, we can hope to see the first step towards unification (or not).
- These are formally higher order corrections from the new states in loops; at very high momentum transfer, the dominant effect comes through the modification of the running coupling.
- We find that over the life-time of the LHC, one can distinguish SM from SUSY running at the few σ level.
  - pp -> W -> eν   pp -> Z,γ --> ee   pp -> γj
- If one imagines that some (but not all) of the MSSM is discovered at the LHC, this provides some indirect information about the parts of the spectrum that has not yet been directly observed.





EW Precision Measurements and Light KK states in Warped Extra Dimensions

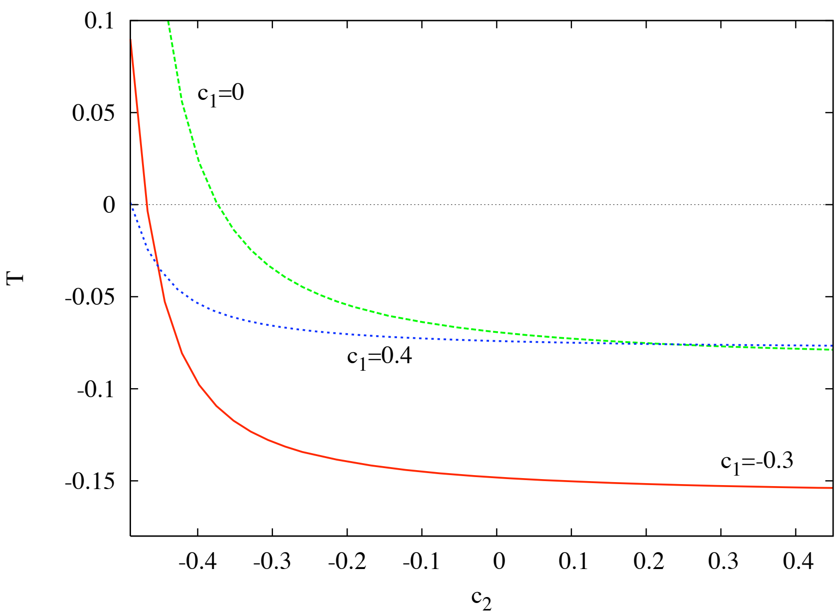
M.~Carena, E.~Ponton, J.~Santiago and C.~E.~M.~Wagner,
Nucl.Phys.B759:202-227,2006 and hep-ph/0701055

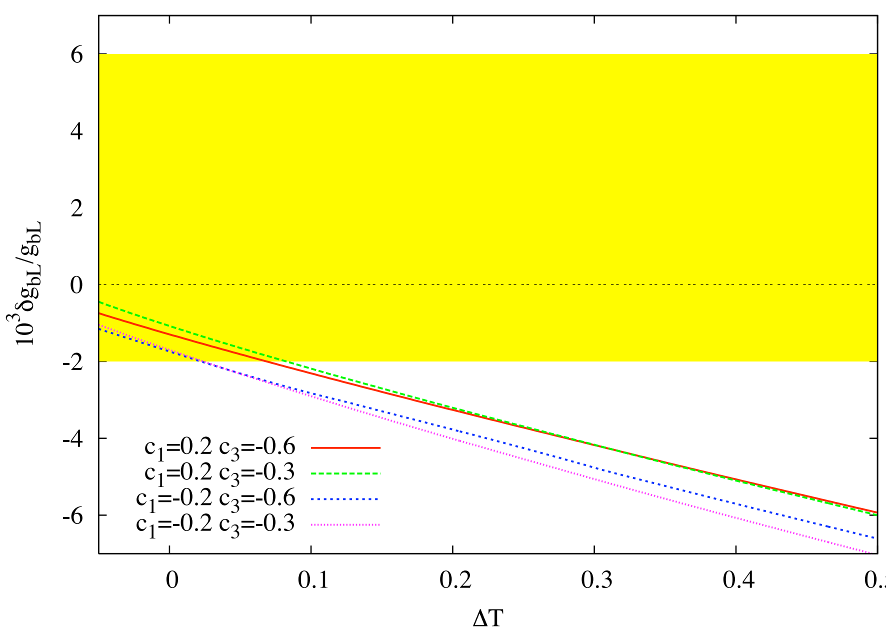
Model based on an extended custodial symmetry, leading to small corrections to the T parameter and the Z-coupling of bottom quarks.

$$\xi_{1L} \sim Q_{1L} = \begin{pmatrix} \chi^u_{1L}(-,+) & q^u_L(+,+) \\ \chi^d_{1L}(-,+) & q^d_L(+,+) \end{pmatrix} \oplus u'_L(-,+) \ ,$$

$$\xi_{2R} \sim Q_{2R} = \begin{pmatrix} \chi^u_{2R}(+,-) & q'^u_R(+,-) \\ \chi^d_{2R}(+,-) & q'^d_R(+,-) \end{pmatrix} \oplus u_R(+,+) \ ,$$

$$\delta(L-y)\left[\hat{M}_u \bar{u}'_L u_R + \text{h.c.}\right] \ .$$





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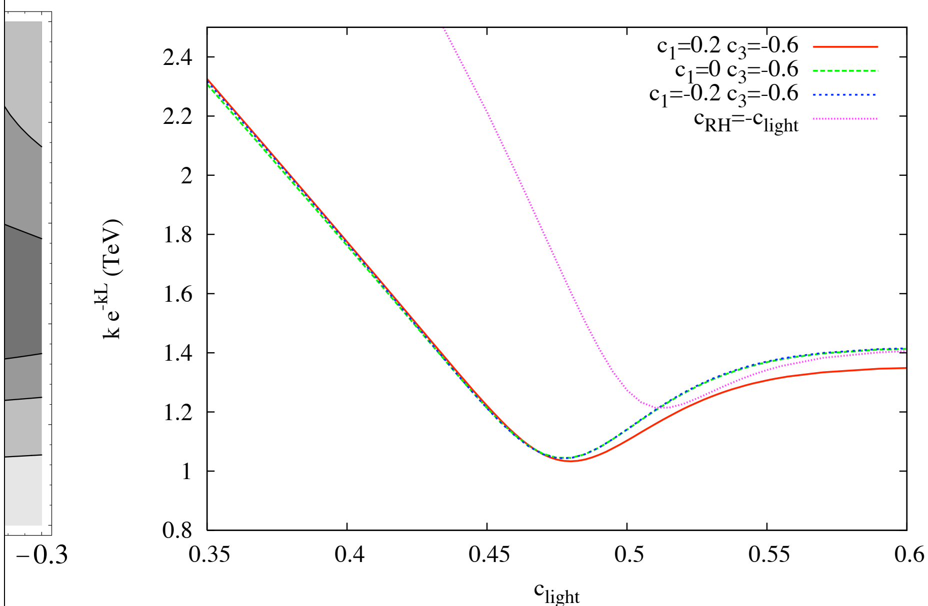
M.~Carena, E.~Ponton, J.~Santiago and C.~E.~M.~Wagner,
Nucl.Phys.B759:202-227,2006 and hep-ph/0701055

Leads to possibly light KK states, with very rich LHC phenomenology



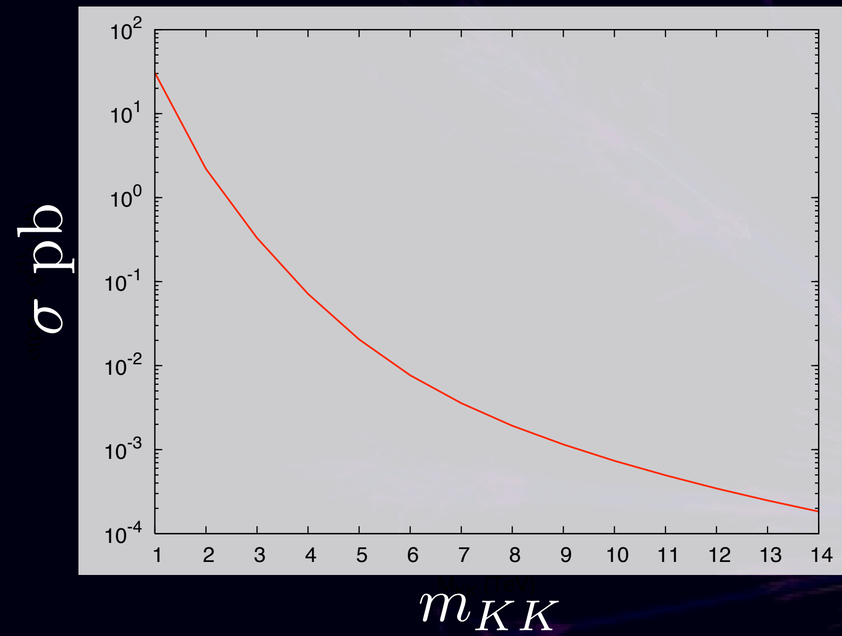
q'	Q	$m_{q'}$ (GeV)	decay
q_1	$\frac{2}{3}$	369	$q_1 \to Zt$, (20%) $q_1 \to Ht$, (60%) $q_1 \to Wb$, (20%)
q_2	$\frac{2}{3}$	373	$q_2 \to Zt$, (9%) $q_2 \to Ht$, (70%) $q_2 \to Wb$, (21%)
u_2	$\frac{2}{3}$	504	$u_2 \to Zt$, (13%) $u_2 \to Ht$, (40%) $u_2 \to Wb$, (41%) $u_2 \to Zq_1$, (1.5%) $u_2 \to Wq'^{d_3}$, (2.5%) $u_2 \to W\chi_2^{u_3}$, (2.%)
$\chi_2^{u_3}$	$\frac{5}{3}$	369	$\chi_2^{u_3} \to Wt$, (100%)
q'^{d_3}	$-\frac{1}{3}$	369	$q_2'^{d_3} \to Wt$, (100%)

$$pp \to q_{5/3,-1/3}\bar{q}_{5/3,-1/3} \to W^+tW^-\bar{t} \to W^+W^+bW^-W^-\bar{b} \to \mu^+\mu^+e^-e^-b\bar{b}\,\not{E}_T,$$

$$q'\bar{q}' \to W^+W^-t\bar{t} \to W^+W^+W^-W^-b\bar{b}\ .$$

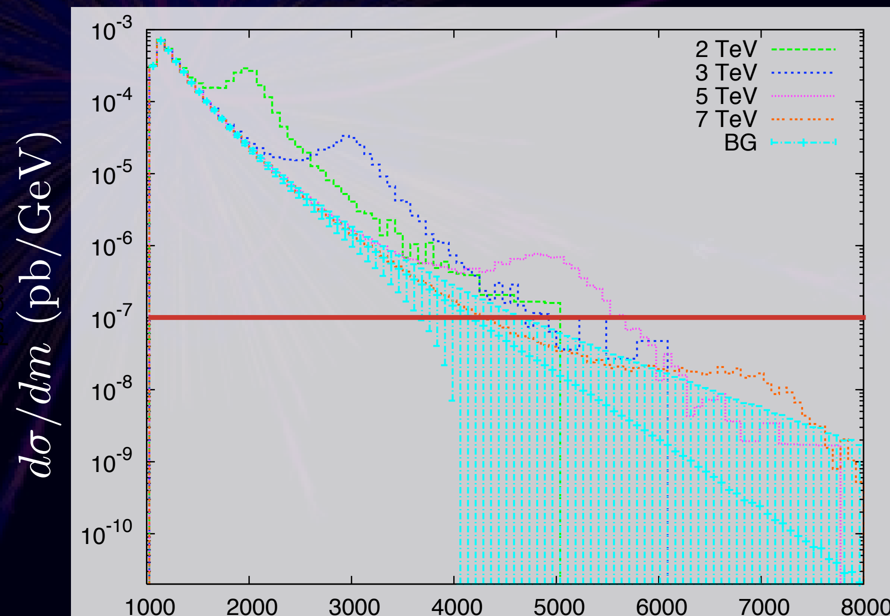
B. Lillie, L. Randall, L. Wang hep-ph/0701166

Top pairs from KK gluons



Cross-section at LHC reasonable, limited by small coupling to light fermions, and lack of glue-glue coupling

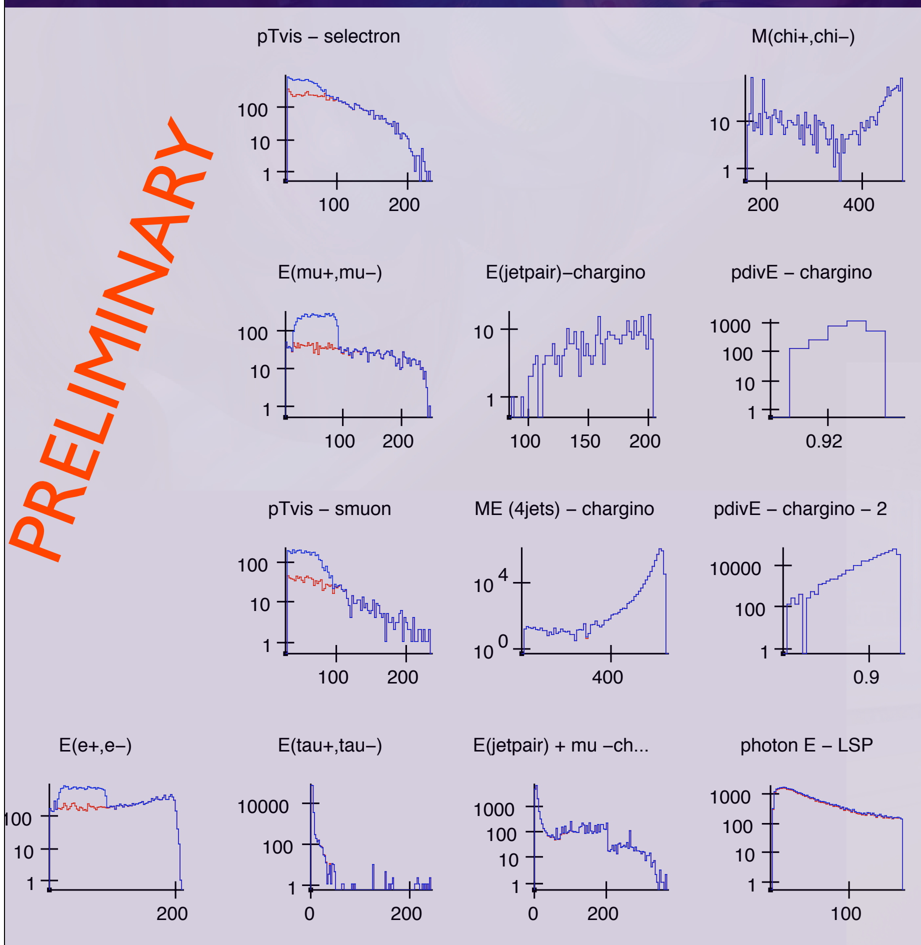
- Nice signal above SM top production
  - PDF and stat. errors shown, assuming $100 fb^{-1}$
- Width/Mass ~17%

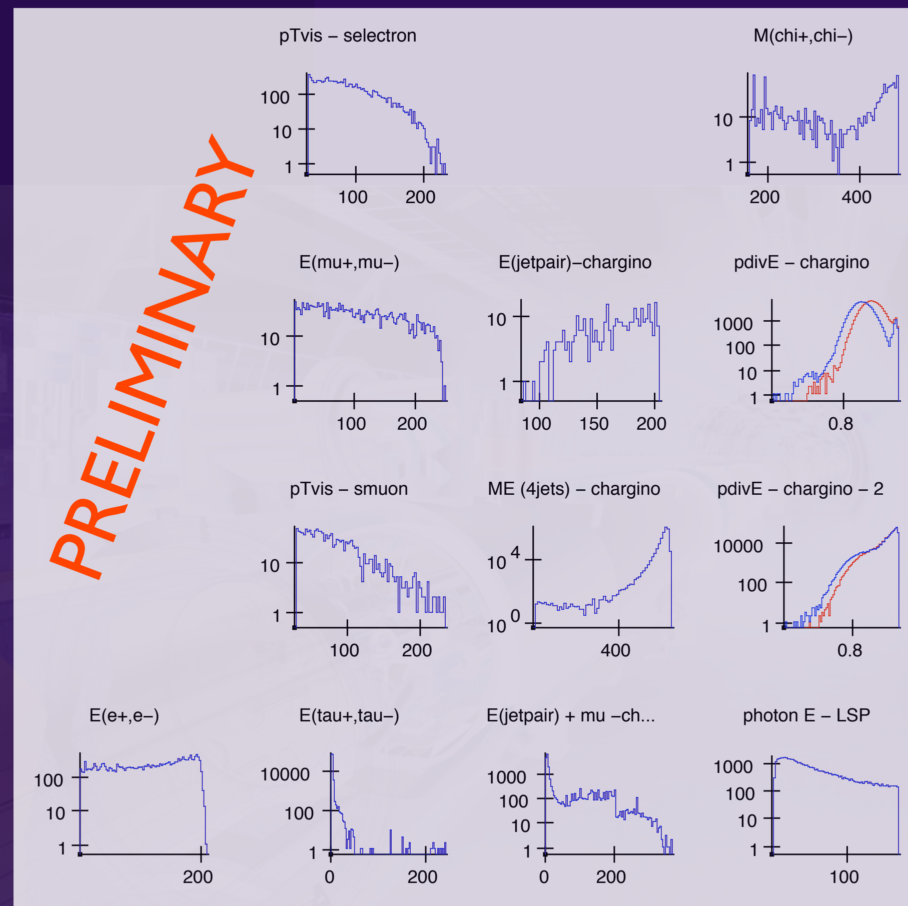


C.F. Berger, J. Gainer, J.L. Hewett, B. Lillie, T. Rizzo

Can the ILC invert the LHC?

Model comparisons





Abstract Physics

A CLASSICAL BOUND ON QUANTUM ENTROPY

$$\boxed{0 \leq S_q \leq \ln\left(\frac{e\sigma^2}{2\hbar}\right)}$$

involving the variance σ^2 in phase space of the **classical** limit distribution of a given arbitrary **quantum** system. No Hamiltonian required!

An **upper bound on the lack of information**. Black Hole entropic behavior: collective flow of information in need of robust estimates. $\leadsto$ Through gross geometrical and semiclassical features of the system— instead of toilsome, subtler, detailed accounts of quantum states.

$\leadsto$ **Combines** upper bound for the entropy of classical continuous distributions (Shannon, 1949) with classical limit of any quantum systems in phase space (Braunss 1994). Tracks the information loss involved in smearing away quantum effects. $\leadsto$ The quantum entropy of a system is majorized by that of its 'ignorant' classical limit.

• **Illustration** by the paradigm of a thermal bath of oscillator excitations of one degree of freedom: The Wigner Function of **arbitrary** half-variance E,

$$f(x,p,E) = \frac{e^{-\frac{x^2+p^2}{2E}}}{2\pi E} = e^{-\frac{x^2+p^2}{2E} - \ln(2\pi E)}.$$

Defining an "inverse temperature" variable $\beta(E,\hbar)$, $\tanh(\beta/2) \equiv \frac{\hbar}{2E} \leq 1$
$\Longrightarrow \quad \beta = \ln \frac{E+\hbar/2}{E-\hbar/2}$,

$$\boxed{S_q(E,\hbar) = \frac{E}{\hbar} \ln\left(\frac{2E+\hbar}{2E-\hbar}\right) + \frac{1}{2}\ln\left((\tfrac{E}{\hbar})^2 - \frac{1}{4}\right) = \frac{\beta}{2}\coth(\beta/2) - \ln(2\sinh(\beta/2)).}$$

↬ **monotonically nondecreasing** function of E, attaining the lower bound 0 for the pure state $E \to \hbar/2$ ($\beta \to \infty$, zero temperature). The classical limit, $\hbar \to 0$ ($\beta \to 0$, infinite temperature) follows,

$$S_q \to 1 + \ln(E/\hbar) = \ln(\pi e 2E) - \ln h = S_{cl}(E) - \ln h \ .$$

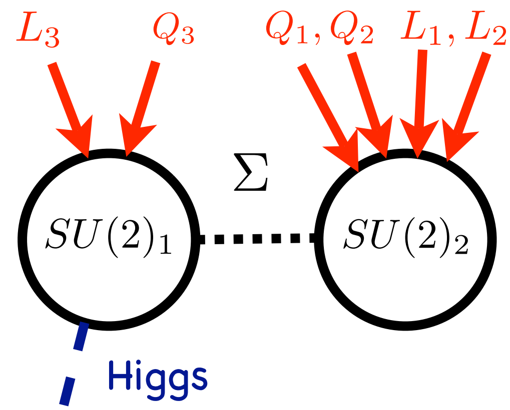
Bounds above expression for all E; saturates it for large $E >> \hbar$.

⫛ Applications in holographic BH physics and quantum computing; LHC contact with gravitational physics confronting quantum randomness. Compton wavelength invisible inside its own Schwarzschild horizon.

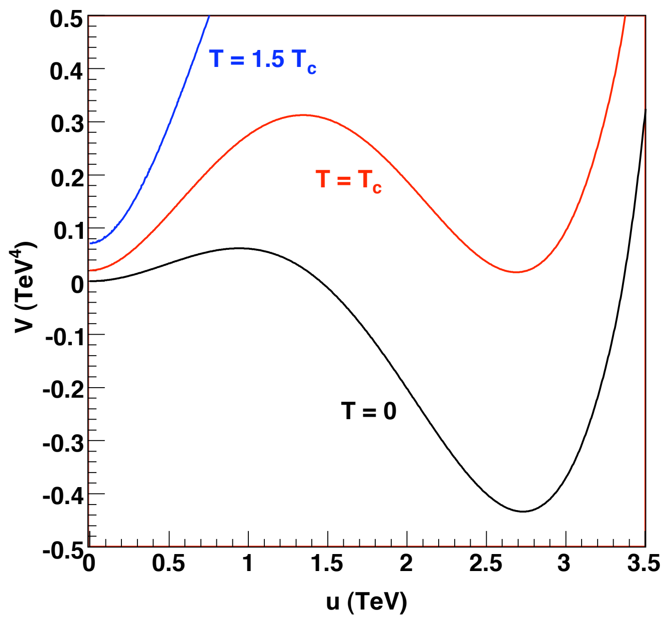
Cosmology

Baryogenesis from an Earlier Phase Transition

Shu, Tait, Wagner
PRDD75, 063510 (2007)



- Baryogenesis from a phase transition requires the phase transition be strongly first order. A major obstacle to EW baryogenesis is the fact that in the SM the EW phase transition is predicted to be second order.
- We explore an SU(2) gauge extension of the SM, and use the strongly coupled instantons of the extended interactions to distribute lepton number unevenly through the three families at the time the theory transitions to the SM gauge symmetry.
- We find parameters of the extension leading to a first order phase transition, and compute the

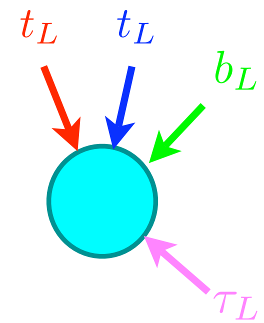


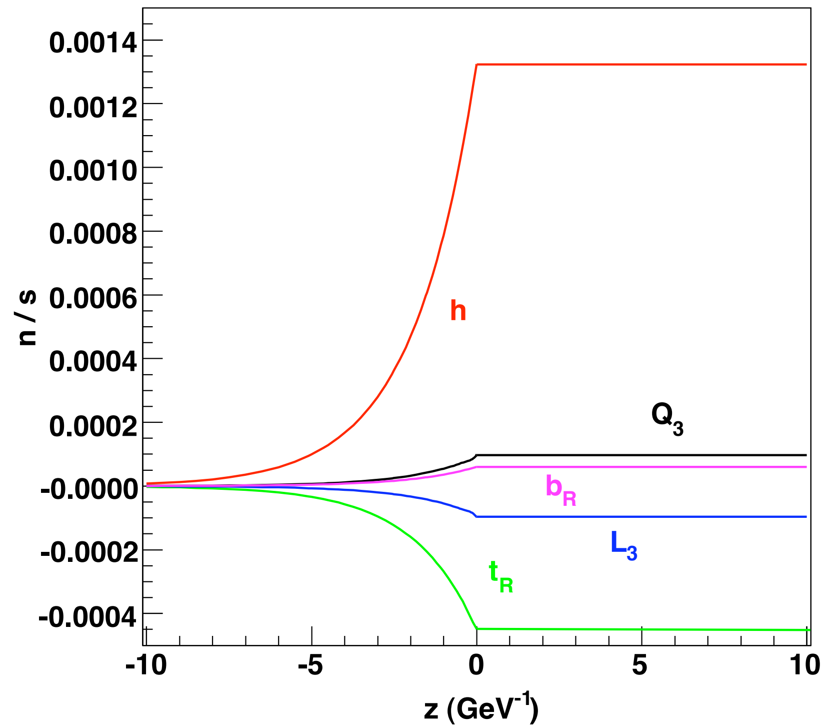
Baryogenesis from an Earlier Phase Transition

- We solve the coupled differential equations describing the particle number densities near the surface of the bubble.
- An uneven distribution of lepton number is produced in each of the three families, because the SU(2)1 sphalerons only couple to the third family.
- Neutrino masses are too small to allow the lepton number to equilibriate between the three families by the time of the ordinary EW phase transition.
- At that point, the finite charged lepton mass effects transfer some of the lepton number into baryon number through ordinary EW sphalerons.

$$B = -\frac{4}{13\pi^2}\sum_{i=1}^{3}\left(L_i - \frac{1}{3}B\right)\frac{m_{\ell_i}^2}{T^2}$$

Morrissey, Tait, Wagner, PRD72, 095003 (2005

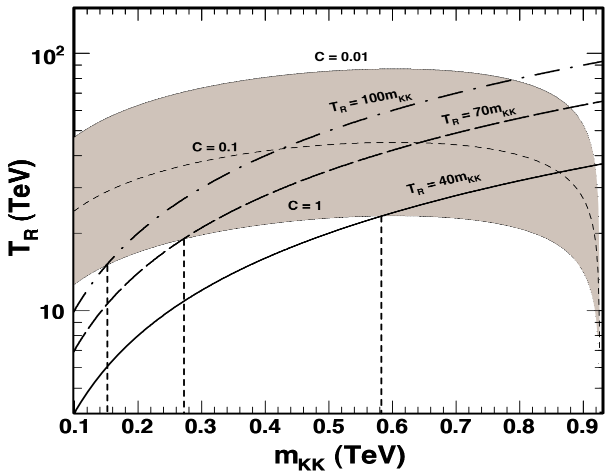


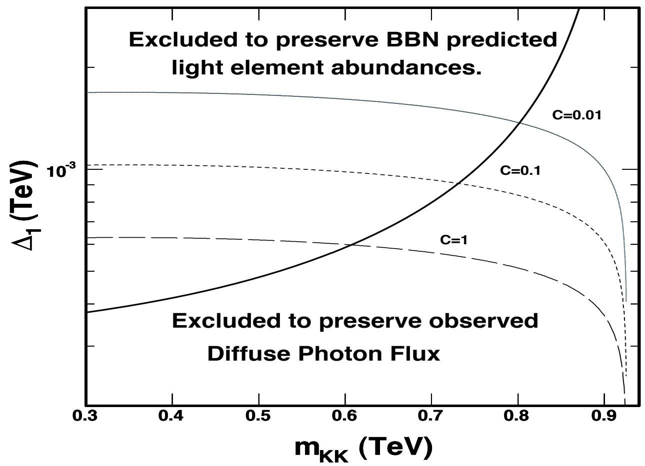


Gravitons and Dark Matter in Universal Extra Dimensions

Nausheen Shah and C.E.M. Wagner, Phys.Rev.D74:104008,2006.

- In UED models, the LKP is a good candidate for dark matter.
- We included gravitons, usually ignored in UED models, and found:
  - Gravitons may contribute significantly to dark matter density, depending on reheating temperature.
  - Limits on Δm between gravitons and LKP (using BBN and diffuse gamma ray flux.)





Soft Leptogenesis in Warped Extra Dimensions

Anibal Medina and C.E.M. Wagner, JHEP 0612:037,2006.

5 D Supersymmetric warped extra dimensions.

Generate B at tree level through radion F-term and A at one loop level.

CP asymmetry and decay out of equilibrium. Small B can be obtained.

$$\frac{n_B}{s} = -\left(\frac{24+4n_H}{66+13n_H}\right) Y^{\rm eq}_{\tilde{\nu}_R}\xi \left[\frac{4\Gamma|B_4|}{4|B_4|^2+\Gamma^2}\right]\frac{|A_4|}{M_4}\sin(\phi)$$

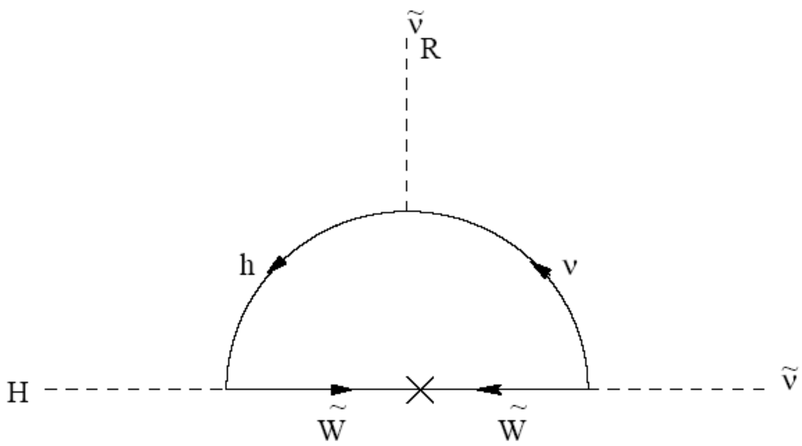


Figure 1: Feynman diagram for A_4 generation.

Input 1			Output 1		
c_{ν_R}	$=$	-0.12	λ_4	$=$	1.98×10^{-5}
kR	$=$	8	$ke^{-k\pi R}$	$=$	1.216×10^{7} GeV
M_1	$=$	3×10^{14} GeV	$M_{4,UV}$	$=$	9.23×10^{6} GeV
M_2	$=$	1×10^{10} GeV	$M_{4,IR}$	$=$	0.73 GeV
k	$=$	1×10^{18} GeV	m_{λ_1}	$=$	484 GeV
λ	$=$	$0.32/\sqrt{k}$	A_4	$=$	70.11 GeV
η	$=$	10^{-3}	m_ν	$=$	1.29×10^{-3} eV
			B_4	$=$	0.0019 GeV
			Γ_4	$=$	0.00029 GeV
			ϵ_L	$=$	1.12×10^{-6}
			$m_{3/2}$	$\approx$	20 eV
			M_4/λ_4^2	$=$	2.44×10^{16} GeV
			$N_{\rm KK}$	$=$	0.55
			n_B/s	$\simeq$	7.2×10^{-11}

Table 2: Results

New Initiatives

What would we do if we had additional funds ?

Hadron Collider Physics Initiative

(based on proposal by E. Berger and S. Kuhlmann)

LHC/QCD Initiative

- Request new funds from DOE to support a first-class, interactive Assistant Physicist who will
  - perform state-of-the-art calculations of the production dynamics of SM and new physics processes at the energy of the LHC, along with SM backgrounds to new physics processes
  - interact closely with internal and external users of the LHC ATLAS data analysis center
- Strong support from external reviewers at the close-out of the DOE review in March 2006 for this type of initiative and for theory group involvement with the ATLAS data analysis center
- Initiative represents an investment in the strong interactions side of LHC collider physics both nationally and at ANL – should appeal to DOE
- Entirely consistent with, and benefits from, the LHC Theory Initiative led by Uli Baur et al, and it provides DOE a vehicle for contributing to this effort

Goals/Research/Person

- LHC is the premier international HEP effort; the US is heavily invested in the LHC and DOE will be judged on its success; ANL and the UoC are heavily invested in ATLAS and we will be judged; breakthrough discoveries are expected; ANL is host to one of the 3 national ATLAS data analysis centers; there is a real opportunity for ANL leadership with the recognition (and funding) that comes with such leadership; theory has an essential role to play
- LHC opens a new energy region with access to much higher p_T, much smaller parton x, and new physics processes; the production dynamics for SM physics changes from quark-antiquark dominance to glue-glue dominance in some processes ($t\bar{t}$ production), but not in others. Simple extrapolation from the Tevatron is not a good guide
- New physics processes will flourish with the increased energy, and theory guidance is needed on expected production aspects and signal discrimination

Comments on Goals/Research/Person, continued

- What we know now about many ingredients in QCD calculations, such as multi-parton amplitudes; higher order 'corrections'; resummation to deal with large logarithmic contributions in important parts of phase space; NNLO parton distributions (PDFs) at small x and large p_T, and event generators, must mature
- Seek a person who will rise to these opportunities and challenges at ANL and become a recognized leader nationally, with well cited publications and speaking invitations
- Funding agencies are responding to initiatives in order to make an impact with limited funds – this LHC/QCD initiative should appeal to the agency
- Practical terms: ANL Lab Director's Office may have to bankroll the first year or two, with DOE agreeing to carry on afterward

Astrophysics Initiative

- HEP Division is joining the Lab-wide Astrophysics Initiative

- Full time theorists working on these issues are present at other National Labs like Fermilab and LBNL.

- Already the two youngest HEP theory faculty members, as well as some postdocs and students have done relevant work on different aspects of cosmology.

- A new HEP Theory person, working on astroparticle physics and cosmology could provide an important and interesting new direction to the group, and can provide a supportive role to the newly created HEP experimental groups in this area.

Recently approved Astrophysics Strategic LDRD Initiative may serve to fulfill this goal

Conclusions

- Theory Group has been very productive on a broad range of areas, including QCD, collider, Higgs, BSM and quarkonia physics, lattice gauge theories, mathematical physics and cosmology.
- The Group has contributed to the formation of numerous postdocs and students, who, in most cases, have carried successful careers after their stay at Argonne.
- It has remained quite active in community services and has very positively contributed to make Argonne the excellent research place it clearly is.
- Activities of the group have been partially supported by (temporary) Grants and collaboration with local Universities.
- Strong need to reestablish the necessary level of base program support to ensure the proper functioning of the group, at a level comparable to other National Laboratories (three postdocs and a rich visitor program)

Lattice Gauge Theory Effort (not reported)

The universality class of lattice QCD with staggered quarks

D. Sinclair, J. Kogut (DOE)

- Simulate lattice QCD with 2 flavours of massless staggered quarks on $N_s^3 \times 8$ lattices ($N_s = 12, 16, 24$) – finite temperature.
- Use χQCD action to allow $m_q = 0$: needed to study the phase transition.
- Universality class of transition to quark-gluon plasma is expected to be $O(2)$.
- Fits of lattice QCD 'data' to $O(2)$ spin model measurements are consistent with $O(2)$ universality for lattice-QCD finite-temperature transition.
- Extrapolations to infinite volume are unnecessary – fit to spin model, also at finite volume.

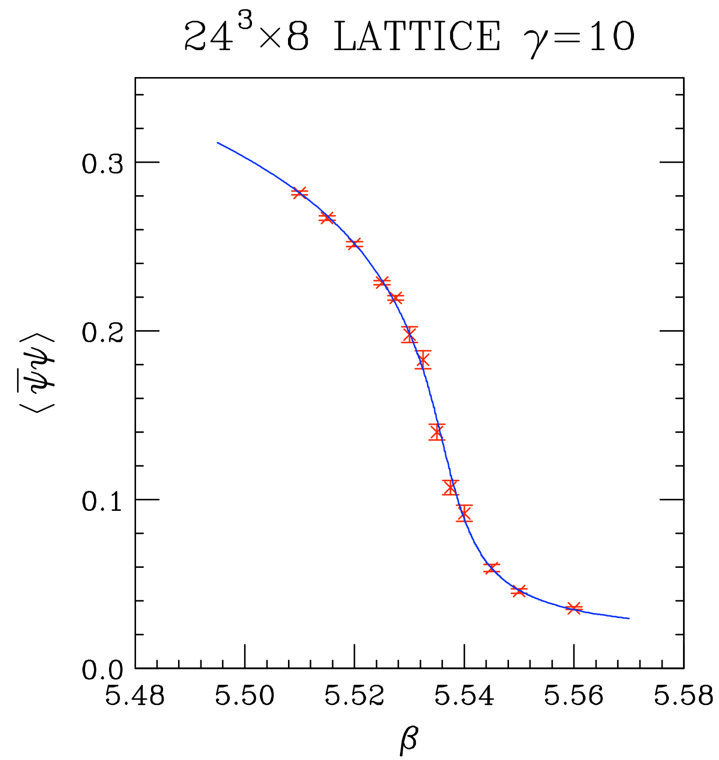


Figure 1: Fit to O(2) spin model

QCD at finite temperature and density

D. Sinclair, J. Kogut (DOE)

- We simulate 3-flavour lattice QCD at finite temperature and small isospin density – closely related to QCD at finite temperature and baryon-number density.
- We search for the critical endpoint at quark mass just above the critical value.
- Early simulations by all groups gave false signals for the critical endpoint.
- Discretization errors in HMD algorithm are much larger than anyone expected.
- We now simulate using the new RHMC algorithm which has no such errors.
- No evidence is found for the critical endpoint. If it exists, it is not related to the critical quark mass, contrary to what others had suggested.

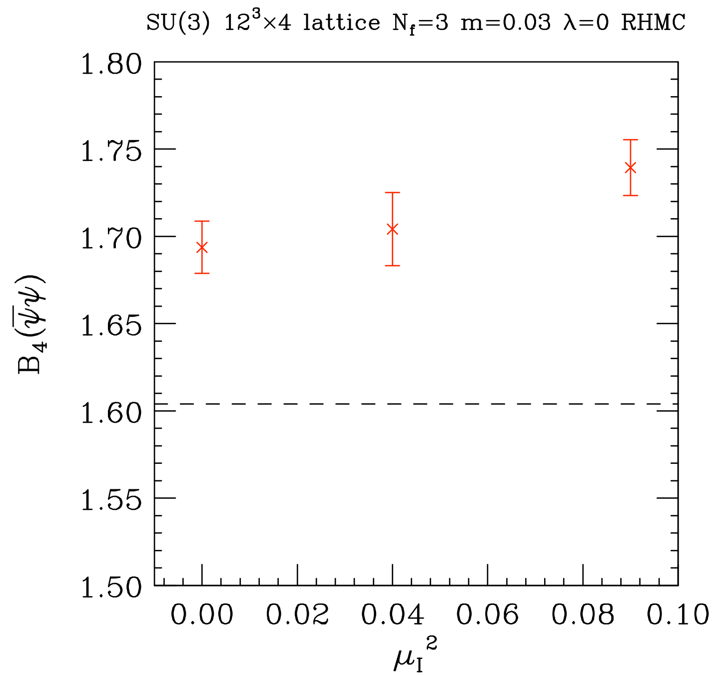


Figure 2: Binder cumulants at T_c